

Breeding for sustainable palm oil¹

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Abstract

As an actor of a supply chain, seed producers must take into account the impact of their work on sustainability. This is particularly true when one works on oil palm, a highly sensitive crop which is questioned on its social and environmental impact. Breeders act directly on yield, thus increasing profitability, while for the same production decreasing land-use pressure. In addition, breeders act on duration of the plantations - which is critical for a perennial crop - making strategic choices by selecting for durable lasting resistances to diseases. They can seek rustic selections, which help the work of small holders and enable them to a better social insertion in the supply chain. In the long trend, the promotion of sustainable palm oil is an excellent opportunity for palm oil seed distributors.

Key words: Oil palm, Breeding, Disease Resistance, sustainability.

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1 Introduction

In 2010, the French « Oléagineux, Corps gras et Lipides » publication has printed a special issue dedicated to sustainable palm oil. (Volume 17, N° 6 ; november-december 2010, Dossier : Oil Palm and sustainable development). The present communication will have large overlapping with our paper on breeding for sustainable palm oil and social responsibility (Durand-Gasselin *et al.* 2010).



Picture 1: Natural palm grove, Dabou road planted around 1880. (Picture T. Durand-Gasselin).

Cultivation of the oil palm starts very likely a long time ago. Unfortunately it is very difficult to trace the entire history. The first documents on oil palm plantation are found in the first part of the 19th century. The king Abomey Guézo (1818-1858) has developed an oil palm plantation in order to maintain the resources of the state, deprived of the slave trade. These plantings were probably encouraged by numerous trade missions conducted by Europeans between 1840 and 1860 (Jannot, 2001). In Cote d'Ivoire (Ivory Coast) one can still found plantations planted at the end of the 19th century with palm the natural grove (Picture 1). It is only a little later, in Asia, that the first real act of selection has been made. (Lubis, 1988)

We reminded the main stages of the selection of oil palm in 2002 (Durand-Gasselin *et al.*, 2002). By 2005, the impact of oil palm breeding on oil palm plantations sustainability has been questioned (Cochard *et al.*, 2005). We will highlight here the main aspects of breeding practices, such as objectives and technical choices, which have an influence on the sustainability of oil palm plantations.

2 Breeding for sustainability in oil palm

2.1 How does the breeder take sustainability into account?

To question its scientific practice should certainly be one of the most important aspects of the work of a researcher: there is a need to set targets that may be consistent with the expectations of the society. He probably has to be assisted in its choices by the emergence of a widely shared awareness, lens through which he will revisit his work and will make every effort to address the social issues. Sustainable development is clearly a global issue that is formalized and is available in many areas. How our breeding activities fit into this framework? For many of us who work on oil palm, there is nothing really new, accustomed we are, as perennial plant breeders, to long and very long outlook and inevitability confronted to duration.

Beyond “duration”, sustainability is also the search for a viable business ("sustainable") which comes with better economic and social connotations, and the welfare of the oil palm grower. Sustainability does also take into account interactions with the world beyond the plantation: the ecological integration, social and economic positioning. Sustainability is at the junction of these dimensions.

By offering high-performance planting material regarding different characters such as field performance (yield), performance of labour (ease of harvest), mill performance (extraction rate), yield of the refinery (olein content), the breeder can put significant added-value throughout the production chain of palm oil including its primary processing. Working on disease resistance will enable the use of the same land for several generations and will help to reduce pressure on land, especially if yields are also rising. The relationship between the quality of planting material and social equity is probably more difficult to assess but should be discussed: can the type of planting material influence the development model for smallholder or agro-industry?

However, one should not imagine that breeders will give solutions to all expectations and all the negative impacts of oil palm. At first, the genetic progress on yields is insufficient even for the best breeding programs (1 to 1.5% per year) to meet the increasing needs for vegetable oil (+ 3-4%) in general and in palm oil in particular (5-6%). Good agricultural practices, integrated management of diseases (in which genetic is involved) are also very important aspects.

Finally, if the rate of development of the vegetable oil consumption continues at the same speed it will be inevitable to further increase the cultivated area.

Tables 1 and 2, however, illustrate (once again) the tremendous potential of oil palm to cover these needs with a very low environmental impact, provided that one choose areas of development. It should be focused on the rehabilitation of degraded lands or pastures. It is part of the responsibility of states to organize and control this development.

For example, in the past 20 years it has been produced an additional 34.5 million tons of palm oil for an extra acreage of 8.55 million hectares as compared to 20 million tons of soybean oil, for an extra 48 million hectares and 13 million tons of rapeseed oil for an extra 13 million ha. Yield progress is also quite different (respectively 24%, 20% and 43%) and will have to be analyzed in detail (not in this paper).

Table 1: acreage development (x 000 ha) for the main oil crops in the world (ref. Oil World)

	1990	1995	2000	2005	2009
Oil Palm (1)	3 560	4 690	6 560	9 187	12 117
Soya	54 910	61 960	75 260	92 813	102 400
Sunflower	16 200	20 230	19 740	23 207	23 810
Rapeseed	17 790	24 520	25 260	27 371	31 030
Cotton	33 920	35 150	32 210	34 251	30 900
Groundnut	19 910	20 590	22 560	22 523	20 910
Coconut	8 940	9 210	9 570	9 270	9 540

(1) Productive land only.

Table 2: Crop development rate and yield for the main oil crops in the world; (ref Oil World)

	Oil production (Tons x 1000)					Oil yield (Tons/ha)				
	1990	1995	2000	2005	2009	1990	1995	2000	2005	2009
Oil Palm (1)	10 710	15 201	21 861	33 847	45 263	3,01	3,24	3,33	3,68	3,74
Soya	15 760	20 231	25 562	33 567	36 016	0,29	0,33	0,34	0,36	0,35
Sunflower	7 900	8 635	9 743	9 821	13 099	0,49	0,43	0,49	0,42	0,55
Rapeseed	8 720	10 631	14500	16 292	21 604	0,49	0,43	0,57	0,60	0,70
Cotton	3 860	3 875	2 850	5 007	4 714	0,11	0,11	0,12	0,15	0,15
Groundnut	3 800	4 252	4 539	4 513	4 208	0,19	0,21	0,2	0,20	0,20
Coconut	8 940	9 210	9 570	3 255	3 226	0,34	0,31	0,34	0,35	0,34

Consider new selection criteria is a long and difficult process. One must be sure that the new selection criteria will remain valid in the long run, it may be necessary to define selection tools (how to measure this character), to assess the available genetic diversity, to study the heritability of the character and its possible impact on breeding methods. Without doubt we must also measure an expected investment/benefit ratio.

2.2 Breeding for yield.

In a previous paper we have identified three major periods of genetic improvement for yield (Rosenquist, 1985; Hartley, 1988; Durand-Gasselin *et al.*, 2002): mass selection, discovery of heterosis in oil palm and D x P development after the Second World War, and “modern” breeding schemes which are widely used now. The fourth one will be the implementation, as a routine, of MAS and clonal propagation.

2.2.1 Mass selection

In the 1920s, mass selection was carried out in Southeast Asia on estate plantations, in the Belgian Congo by INEAC and in French West Africa by a few growers. After two to five generations, those selections gave what Rosenquist (1985) called “breeding populations of restricted origin” (BPRO)². In Asia, those selections were quite effective, making it possible to set up relatively large estates for the period. In Africa, they were disrupted by the disjunction of the shell thickness trait.

An understanding of the heredity of that trait marked the end of that period (Beirnaert and Vanderweyen, 1941). It was also at that time that the first effective controlled pollination techniques were developed. The strong inbreeding depression in selfs was soon to be reported (end of the 1940s).

2.2.2 The International Experiment (after World War II)

At the initiative of IRHO³, five estates exchanged and intercrossed the best parents from their own selections, as part of what was called the “International Experiment”. It gave some very interesting results (Gascon and de Berchoux, 1964):

- Discovery of substantial variability between the different populations studied.
- The additive nature of the heredity of the number and average weight of the bunches produced by oil palms, an essential yield component.

² Improved populations with a narrow genetic base (e.g.: Marihat, Dolok Sinumbah, Bah Lias in Indonesia; Elmina, Chemara, Socfin in Malaysia; Yangambi, Ekona, La Mé in Africa, and many others).

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- The superiority of between-origin crosses compared to within-origin crosses, particularly when there was complementarity. That result was exploited for seed production (Bénard and Malingraux, 1965).

At the same time the use of D x P crosses were generalized.

2.2.3 “Modern” breeding scheme

Without going back too far in time, we note that gradually only two breeding strategies were developed. They are also quite similar and have both a recurrent pattern (Soh, 1990). We distinguish the reciprocal recurrent selection (RRS) scheme adopted by the NIFOR, the IHRO-CIRAD and its partners in Africa or Southeast Asia, Iopri in Indonesia, Felda in Malaysia and Family / Individuals (FIPS) selection schemes widely used in Malaysia (MPOB and its partners) and Papua (OPRS), Pamol, Unipalm etc.. in Africa (Rosenquist, 1989).

The reciprocal recurrent selection (RRS) aims at exploiting the heterosis existing between the crosses carried out between certain origins and the constraints due to inbreeding depression. IRHO adopted it as early as 1958. The material was divided into two heterotic groups, A and B, based on a complementarity of traits (Meunier and Gascon, 1972).

The FIPS scheme, for its part, take advantage, in the form of D x P planting material, of selected parents based on their phenotypic value and general combining ability and that of their families (Hee Lee Chong and Yeow Kheng Hoe, 1965. Hartley, 1967; Breure *et al.*, 1982).

The main results were:

- Calculation of trait heritability, an overview of which was drafted by Meunier *et al.* (1970).
- A huge genetic progress that has been passed into the D x P seeds. As an example the crosses derived from the International Experiment produced around 2 tons of oil per hectare and the latest selected crosses from the first cycle produced 3.6 tons of oil per hectare under the conditions in Ivory Coast (Gascon *et al.*, 1981 ; Gascon *et al.*, 1988)

2.2.4 Main perspectives

Two different tools are likely to bring tremendous changes in both the planting material and the breeding schemes: the clones and marker assisted selection (MAS).

Tissue culture

Despite 40 years of continuous work tissue culture failed to show all its promises, but the techniques have been improved, the strategy to take advantage of the potential genetic progress have refined (Soh A. C. *et al.*, 2001; Potier *et al.* 2006; Soh A. C. 2010) :

- it is possible to get high-yielding clones that are abnormality-free,
- Phenotypic selection within crosses is rather inefficient: identification of high-yielding clones requires an evaluation phase in field trials. This stage has been reached by some institutions (Felda, Cirad, ASD...)

Another approach consists in cloning one or both parents in order to produce semiclinal (one clonal parent and one sexual parent) or biclinal (both clonal parents) hybrid seeds.

Marker Assisted Selection.

Many tools are currently being developed and the effort of the oil palm scientific community allowed us to expect many applications very rapidly. Identification of markers or, even better, genes underlying agricultural traits is a matter of months. But as phenotypic variation among individuals are quantitative, in deep rethinking of breeding scheme will be needed. The technology is moving fast, the one used today will be replaced tomorrow by a cheaper and more efficient one. Breeding will no longer be a blind science: traits will be gathered within phenotypes on purposes.

2.2.5 Partial conclusion

Figure 1 sums up the last fifty years of genetic progress achieved for oil production per hectare. And new genetic progress will be achieved in the future, improving sustainability of oil palm cultivation. These genetic progresses have had an impact on yields in plantations and in Malaysia, as an example, yield per hectare rise from 1.3 to 5.4 tons of oil, half of which is attributed to genetic (Davidson L., 1993).

Total product (Yield) is by far not the only trait to be improved regarding sustainability:

- Vertical growth has also been largely reduced which, for the same age, facilitates harvesting. As the replanting age is generally determined by the height of the palms, it also becomes possible to prolong the exploitation period by around 5 to 7 years, and especially to have more flexibility in deciding when to replant depending on outside economic criteria (e.g. price of palm oil).
- Oil extraction rate: Palm oil production is a result of bunch production multiplied by their oil content (extraction rate). The latter increases primary processing efficiency and leads to a better return on investments.
- Resistance to diseases is also a priority objective. On every continent serious diseases are rife, and genetic factors of resistance are being sought for each of them.
- ...

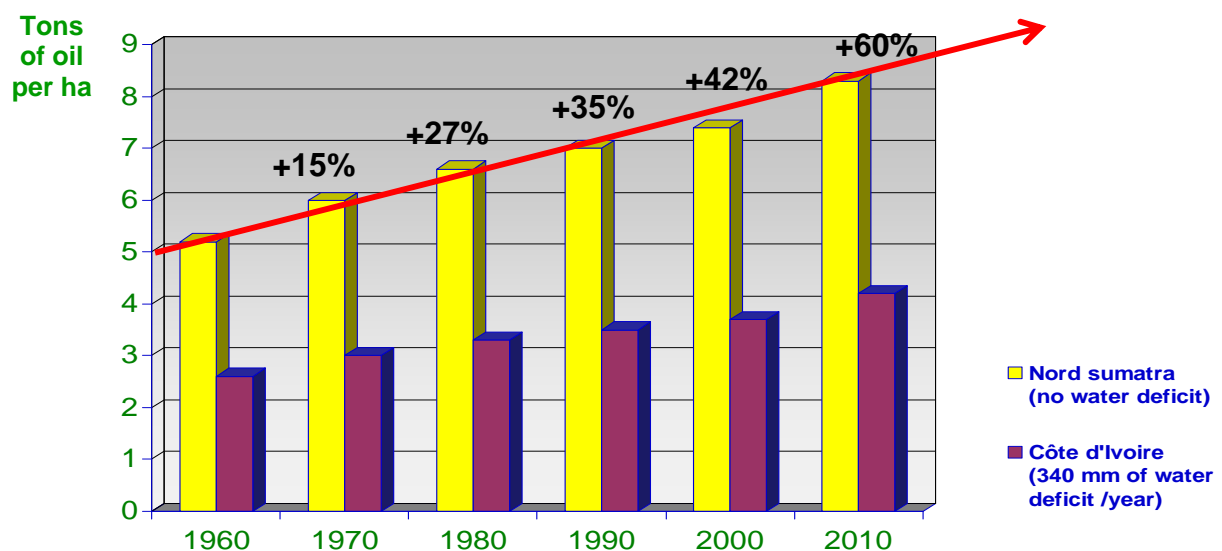


Figure 1 : Evolution of pure genetic potential of the oil palm seeds in Indonesia (no moisture deficit) and Côte d'Ivoire (340 mm water deficit).

2.3 Breeding for resistance to diseases in oil palm

Oil palm cultivation is threatened by three diseases that have major economic importance. A *Fusarium* (*Fusarium oxysporum* f.sp. *elaeidis*), quite specific to Africa, can cause extremely large losses in plantations (up to 70%) (Franqueville and Renard, 1990). In Southeast Asia *Ganoderma* may caused up to 80% mortality, but this disease is also widely present in Africa, sometimes in combination with *Fusarium*, and spots are emerging in Latin America (Franqueville *et al.*, 2001). In Latin America, bud rot, probably related to *Phytophthora* palmivora, (but it should also be confirmed whether it is in interaction with other pathogens) can cause very rapidly up to 100% mortality (Franqueville, 2003; Martinez , 2008).

For these three diseases, genetic resistance have been identified and are already included in the varieties "resistant" available for planting, or will be in the short term. Resistance to diseases are characteristics that have a major influence on the sustainability of oil palm plantations and which help to secure the planters investment and to ensure long-term profits.

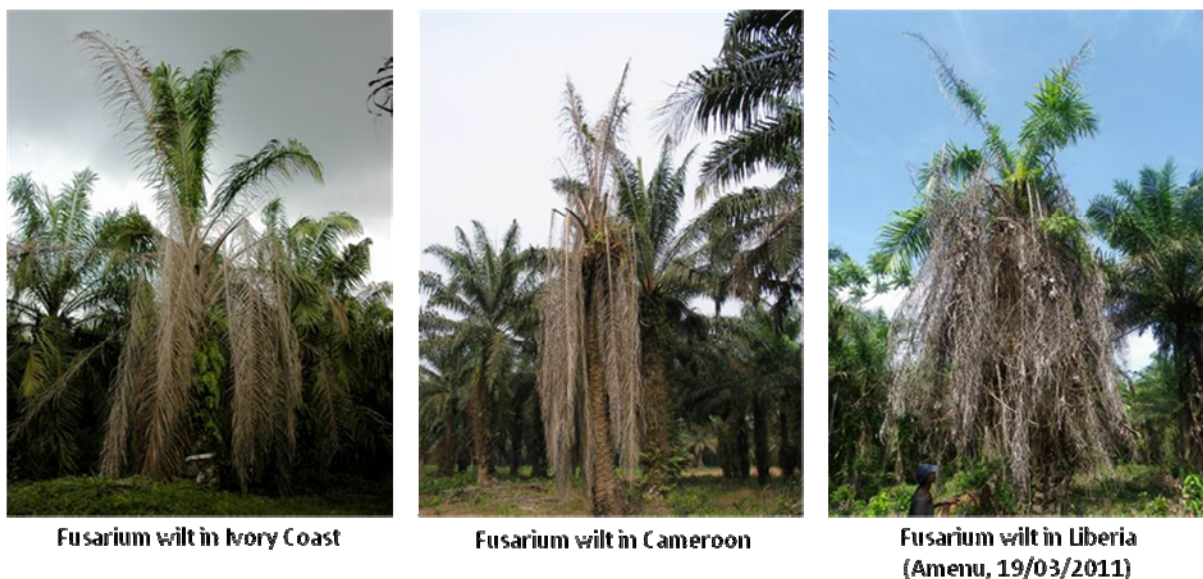
Plant pathologists and breeders do make a clear distinction between total resistance (specific) and partial resistance (non specific). Total resistance generally (not always) results from a gene for gene interaction between the plant and the pathogen. Gene-for-gene resistance is a form of plant disease resistance that is exploited widely by plant breeders. However such a specific resistance can be bypassed easily by the pathogen: for oil palm which is a perennial crop we are therefore not looking for such total resistance.

Our strategy aims at selecting for multiple defense genes involved in partial resistance. This selection will encourage and provide **sustainable** nonspecific resistance to a larger diversity of isolates of the pathogens, rather than single gene for gene resistance. Selecting plants for multiple partial disease resistances will not result in the disappearance of sick plants in the field, but it will be more efficient to limit their number.

Agronomists and planters will most of the time use the word "tolerant" rather than "multiple partial resistances".

2.3.1 *Fusarium* wilt.

H. de Franqueville has very recently summarised the state of the art for *Fusarium* wilt (de Franqueville *et al.*, 2011). *Fusarium* vascular wilt is caused by *Fusarium oxysporum* f.sp. *elaeidis*, a soil-borne fungal pathogen, specific to the oil palm. It is widespread in Western (Picture 2) and Central Africa, where it was first described in the late 1940s. It is considered as endemic in many parts of the continent.



Picture 2 : Fusarium wilt in west Africa

The pathogen penetrates the plant via the root system and can cause a rapid decay of the affected palms. The symptoms, acute or chronic, vary depending on several factors, such as the age of the palm, the crop cycle and the degree of susceptibility of the planting material. Losses of more than 50% can be recorded in some plantations. (Figure 2)

Being a soil inhabitant, the pathogen and its population increase during the first planting, causing damage to the mature palms, but in replantings, *Fusarium* wilt affects young palms. Although some cultural practices can reduce the level of the disease, planting *Fusarium* wilt resistant material is the only viable method of control. Breeding for resistance is therefore of paramount importance and sources of partial resistance can be found within many origins of *Elaeis guineensis* and in addition a very strong resistance factor can be found in some populations of *Elaeis oleifera*.

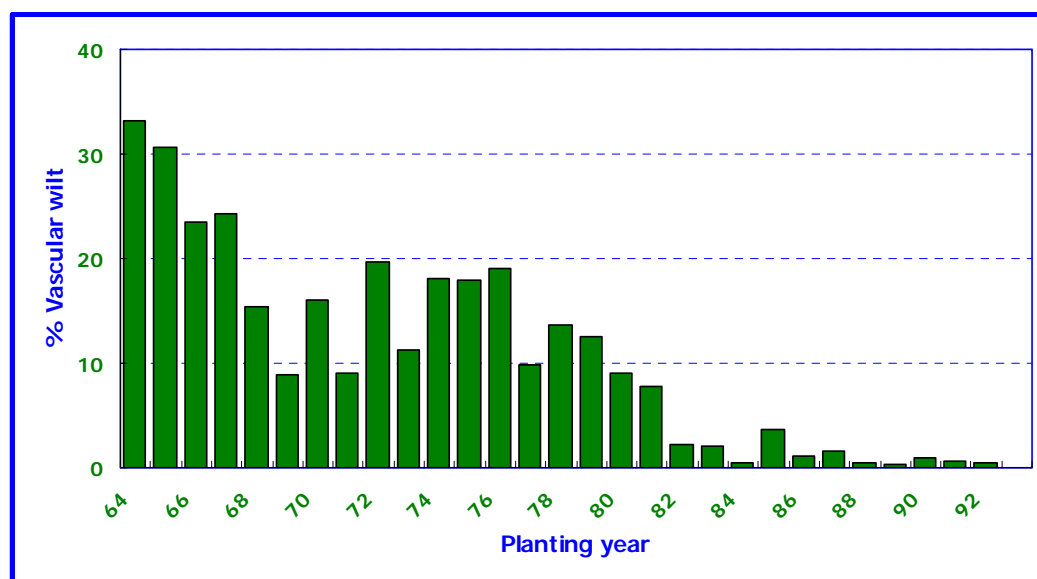


Figure 2 : Evolution of the percentage of palms affected by *Fusarium* wilt in Robert Michaud plantation in Côte d'Ivoire.

It is achieved through an early screening test, based on artificial inoculation of the pathogen. The general consistency of the screening test was proven (de Franqueville, 1984; de Franqueville and Renard, 1990). In Cote d'Ivoire, the losses in a 4000 hectares estate were reduced from 35-40% in the 1960s to 10-15% in the 1970s, and progressively to less than 3 %, with a high amount of recovery, in the 1980s and 1990s (Figure 2). This early screening test is closely correlated to the field behaviour of the planting material (Figure 3) .

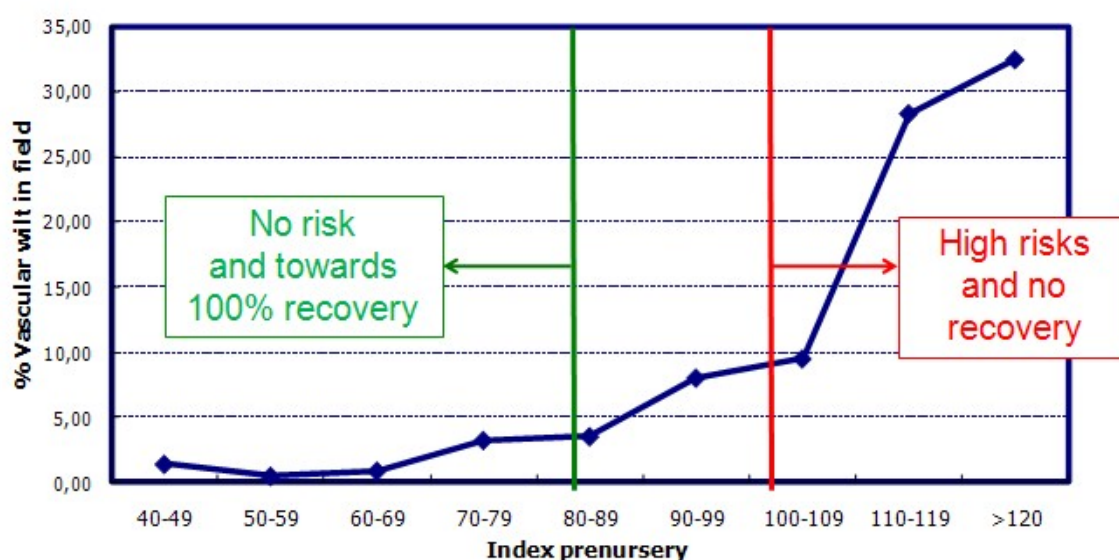


Figure 3 - Relationship between prenursery index and the degree of resistance in the field

Such results are based on several decades of screening, without any interruption. Each year, several hundreds of progenies are screened. In a recent study, Diabaté *et al.* (2010) showed that this low level of the disease prevalence is maintained twenty years later.

Highly resistant and highly productive planting material is available for all plantations in Africa. Today, our research focuses on the exploitation of new sources of resistance in order to broaden the genetic base of the material.

Fusarium wilt is not the only threat for oil palm cultivation in Africa and it appends frequently that old oil palm plantations are also attacked by *Ganoderma* in central Africa. The next step hopefully will be to create a breeding material adapted to this double threat.

2.3.2 *Ganoderma*.

Sources of resistance and susceptibility were found in field trials implemented at Socfindo in North Sumatra (de Franqueville *et al.*, 2001; Durand-Gasselin *et al.*, 2005). Field observations have proven to be consistent, given the genetic and statistical designs on which the trials were based (Figure 4).

The research of *Ganoderma* resistant varieties is much more recent than for *Fusarium* wilt (Breton *et al.*, 2009). It has not yet led to the release of *Ganoderma* resistant varieties, but the present results are very promising.

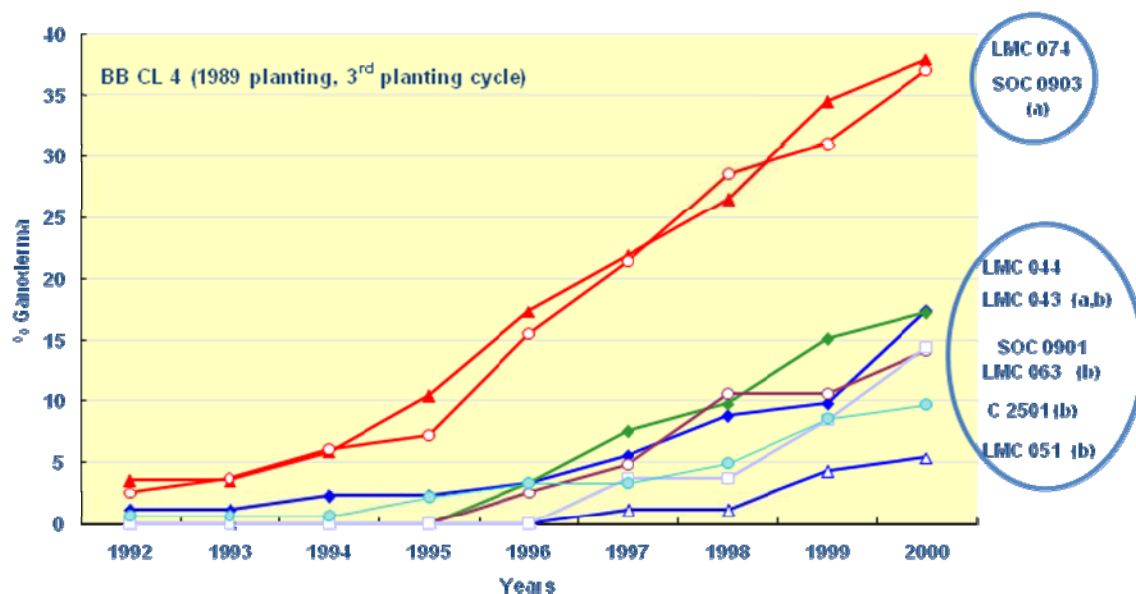


Figure 4: Evolution of the percentage of palms infected by *Ganoderma* in a clonal trial in Indonesia (plantation de Bangun Bandar, Socfindo, Indonesia).

An early screening test has then developed (Breton *et al.*, 2009), inoculation is done in pre-nursery and *Ganoderma* resistance of different origins of oil palm has been assessed. As an example, results for different “African” origins, all crossed with the same Deli origin (used as testor), are given Table 3. The correlation between differences observed in pre-nursery and the one observed in the field has to be assessed but indications are often positive.

Table 3 : Comparison of percentage of infected palms in some « African » pisifera origins crossed with a susceptible Deli testor. (100 palms / tested cross)

B Group	A Group	Nb of pisifera	Percentage of <i>Ganoderma</i> infected palms	Nb of crosses and Nb of tests
Pisifera origin A	Same unique Deli Origin	4	28,2	(11 crosses, 11 tests)
Pisifera origin B		3	29,1	(10 crosses, 11 tests)
Pisifera origin C		3	30,3	(5 crosses, 10 tests)
Pisifera origin D		8	34,5	(15 crosses, 15 tests)
Pisifera origin E		7	35,4	(12 crosses, 12 tests)
Pisifera origin F		4	35,4	(8 crosses, 8 tests)
Pisifera origin G		14	37,5	(18 crosses, 22 tests)
Pisifera origin H		1	37,5	(11 crosses, 11 tests)

In general, there is no connection between resistance to *Fusarium* wilt and resistance to *Ganoderma*, however, we have identified several genotypes that appear to have a good resistance to both diseases.

This double resistance is crucial for Central Africa (Congo Basin, Cameroon) where both diseases are very active. The two diseases have also been found together in West Africa, but in limited spots (Franqueville, personal communication). Among such varieties, some are highly productive so we will not have to compromise on this point.

2.3.3 Bud rot.

“Bud rot” (BR) is a disease with a complex symptomatology. Thus, many have perceived it as several diseases. It has been described in many forms (G. Martinez *et al.*, 2008, C. Louise *et al.*, 2006), which bears witness to a diversity of situations suggesting to us the existence of a primary causal agent, followed by a cocktail of opportunistic microorganisms whose variability appears to be linked to local environmental conditions. For simplification purposes, since the solution is similar, we consider in this article that a single cause with variable symptoms is involved.

In the last 30 years, many hypotheses have been proposed for the cause of this disease (even the possibility that it might not be a disease) and H. de Franqueville has provided an overview of them. More recently, one hypothesis that was initially ruled out, *Phytophthora*, was re-investigated by G. Martinez with some new and very interesting experimental findings.

Resistance of *E. oleifera* to the disease was proven very early, but this palm species does not produce enough oil to be commercially exploitable. With much better oil production, the 1970's plantings of *E. guineensis* x *E. oleifera* interspecific hybrids in severely affected zones, have displayed good resistance to bud rot which has never been challenged since. Van de Lande mentions one hectare of *E. o.* x *E. g.* hybrids planted in 1978 at Victoria, Suriname which has resisted the disease very well, which were still intact by 2007, (J. Corredor personal com). Almost the same story happens at Turbo (Coldesa, Colombia) (J. Corredor personal com.). In the Tumaco region of Colombia there are many plots of old O x G hybrids (Sinu x Yangambi origins) from the 70's that have resisted the recent attack of the disease. (Durand-Gasselin *et al.*, 2009)

Some of pure *E. guineensis* Cirad C07** or C65** materials have shown quite good resistance to the disease in the Eastern zone of Ecuador (table 4 and Figure 5) (Amblard *et al.*, 2009). This partial resistance found in the Deli origin will have to be confirmed and their durability assessed.

Table 4 : Bud Rot mortality of different Deli origin of some *E. guineensis* materials in trials SH GP 9 et 10 (Plantation 2000, Shushufindi, Palmeras de los Ecuador, Equator). Results 9 years after.

Origine Deli	SH GP 9	SH GP 10
DA 8 D AF	68,0	38,1
LM 404 D AF	62,0	37,5
DA 115 D x DA 3 D	51,9	24,6
DA 5 D x DA 3 D	48,8	29,6
DA 115 D AF	47,8	29,2
DA 128 D AF	19,6	9,5

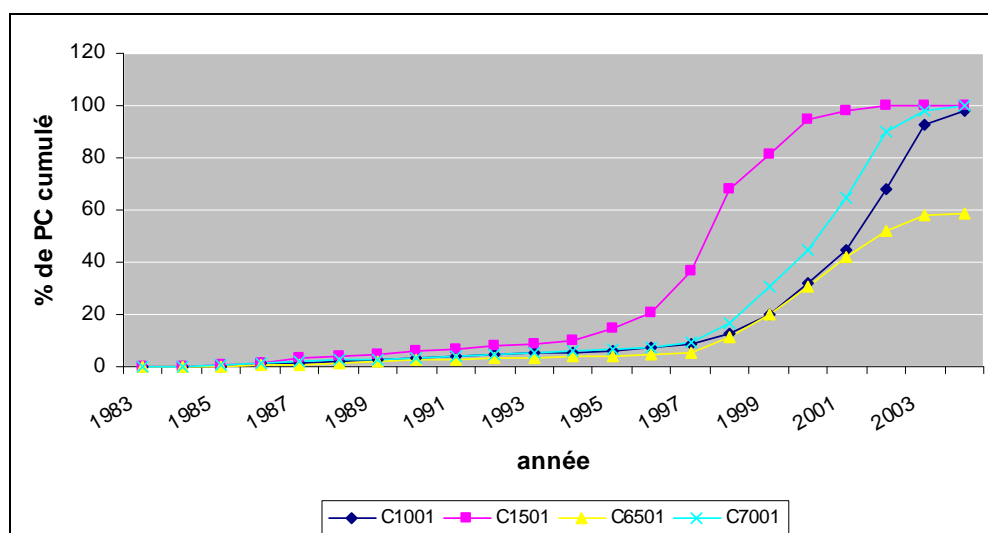


Figure 5: Evolution of bud rot disease in Trial SHGP 1 (Plantation 1983, Shushufindi Palmeras de los Ecuador, Equateur).

It is therefore possible to provide genetic solutions to this disease by combining the partial genetic resistances (whether they are strong or not) found in *E. guineensis* and *E. oleifera*.

Although *Elaeis oleifera* palms have displayed almost total resistance to all forms of BR, whatever their geographical origin, they do not produce enough oil for their cultivation to be profitable. However, *E. oleifera* transmits resistance that is almost as strong to the interspecific hybrid *E. oleifera* \times *E. guineensis* hybrids. Breeders were able to select a few combinations of interspecific hybrids that resulted in very respectable yields.

The different breeding strategies have been discussed recently (Durand-Gasselin *et al.*, 2009), and offer many opportunities to exploit the advantages of *E. oleifera* by combining different approaches: the creation of interspecific hybrids, introgression of certain characters in *E. guineensis*, the in vitro techniques allowed to create clones that will be resistant to the disease (Picture 4).



Picture 4: Field behavior of one *E. guineensis* clone, BTC 40, compared with three commercial *E. g.* varieties (C2501, C1501 and C1001) (Shushufindi plantation, PDE, Ecuador).

The most efficient genetic answer, interspecific hybrid, suffers from a major handicap that is interesting to note in this presentation, since it illustrates how breeding programs can have an influence on certain social aspects of oil palm cultivation.

The pollen produced by the interspecific hybrid is not fertile enough. In addition pollinating insects which are visiting *E. guineensis* or *E. oleifera* inflorescences are not attracted to the inflorescences of the hybrid. Pollination of female inflorescences of the hybrid must be performed manually through assisted pollination. This requires a dedicated organization for harvesting and packaging of pollen that small farmers would find difficult to achieve by themselves. This difficulty could be a major obstacle to the development of hybrid plantation by smallholders excluding them from the production chain. However, we believe that a cooperative organization could help to support the necessary infrastructure.

2.4 Other oil palm breeding objectives related to sustainability.

Other characteristics of oil palm could be improved that will support sustainable development. We can mention them for the record:

- The characteristics of palm oil may change, especially through the use of palm *E. oleifera*, to high levels of unsaturated fatty acids.
- The oil palm produces oil naturally rich in vitamin A (up to 3 %) and vitamin E. Selections are possible on these points to improve the health benefit of oil palm consumption.
- Planting material fertilizer efficiency can be worked out in with agronomists and physiologists.
- it seems possible to select low-palm lipase, and indehiscent fruits, this will introduce flexibility in harvesting organization.

3 Conclusion.

Sustainability is a broad concept that encompasses the values of general interest. It is therefore not surprising to find this notion of transversality in diverse business fields; we have given several examples where sustainability fits well in the heart of the action of the breeders. Genetics contributes largely, but not alone, to enhance the sustainability of palm oil plantations: yield, disease resistance are specific examples.

Through the example of interspecific hybrids resistant to Bud Rot, we have shown how selection could, if left without remedy, have a negative impact on some social aspects of oil palm development.

Beyond the scientific and technical aspects, it is also possible to promote sustainability by improving seed distribution towards small holders. The influence of seed suppliers in this field is certainly indirect, but it has been shown that it is still possible to act alone and with our partners to promote sustainability. We can support the idea among farmers it is certainly an opportunity to improve their yields and incomes while reducing the expansion of their culture to new lands.

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